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OIL FIELDS REJUVENATED

By

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Introduction.

Oil wells cease flowing when only a small part of the oil has been delivered to the surface. Then pumping is resorted to and more oil is obtained. When pumping yields so little oil that it does not pay to continue operating; the supply of oil in the sand is by no means exhausted. In fact, there may remain in the reservoir more oil than has been recovered. Several methods have been devised for bringing this oil to the surface.

The several methods of rejuvenating oil wells may be classed in two groups, those applied to pools or leases, and those applied to single wells. The methods applicable to pools or leases are: (1) the restoration of pressure by water flooding, (2) restoration by compressed air, (3) by dewatering of flooded pools. Methods applied to single wells are: (1) cleaning by chemical or electrical processes, (2) developing upper sands.

As the quantity of oil remaining in seemingly exhausted pools or wells is large, a slight difference in the percentage of oil recovered is important. Therefore the writer was asked to study these methods as applied to oil pools in Pennsylvania and rate the results.

Definition of Terms.

Flooding - the act of letting water (fresh or salt) into a well for the purpose of increasing the production of oil from other wells.

Trapped oil - oil forced aside by the water passing from a flooded well to a producing well.

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Pressure Restoration Methods

Water Flooding.

Flooding is classed as a pressure restoration method because the hydrostatic pressure developed by the column of water standing in the well forces the water to penetrate the sand and to accumulate the oil ahead of it.

Bradford Pool. The Bradford pool is in McKean County, Pennsylvania, and Cattaraugus County, New York. The area, according to Lewis[*] is 85,000 acres. These figures will be used for acre yield calculations. Production began in 1869, and to 1915 the pool yielded 230,000,000 barrels of oil, or an average of 2700 barrels per acre. Estimating an additional production of 21,250,000 barrels to the end of 1920 gives an average yield of 2940 barrels per acre.

Bradford Sand. The stratigraphic position of the producing sand in the Bradford pool is Middle Chemung. Of the physical characteristics of the sand Ashburner[**] says: "The Bradford oil sand is the most important economic stratum in the northern tier of counties. It consists of gray and white sand of about the same coarseness as the ordinary beach sand of the Jersey coast; compact, yet loosely cemented. The average thickness of the sand is about 45 feet, and from top to bottom the sandy strata change but little in their general character. It is only when specimens from successive layers are placed side by side and closely examined that any difference in structure can be noticed. The grains of sand are angular, vary but slightly in size, color, and quantity of cementing material, which holds them together in their rock bed.

The same homogeneousness which characterizes the vertical section is found to exist over a considerable horizontal area. In fact, but little change is found to exist in the sand obtained from wells 15 miles apart, or in the sand from intermediate wells."

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* Lewis, J. O. U.S. Bureau of Mines Bull. 148, p. 108
** Ashburner, C. A. Report R. 2nd Geological Survey of Pennsylvania, 1880 - Page 75.

The porosity of this sand is reported* to average 18 per cent. Structurally, this is one of the flattest oil fields known, dips probably not exceeding 10 feet per mile in any direction.

First flooding. The first purposeful flooding in this district probably occurred about 30 years ago,** and was done with the object of increasing production. The idea probably was conceived from observed results of accidental flooding. When three years elapsed after the water had been let into an old well without appreciable results, the owners sold the property, feeling that their efforts had been futile. The purchaser pumped the wells at a small profit for several years; then being alarmed by the rapidly increasing production of two old wells, and having the common fear of flood, he sold out at a fair profit. The new owners for several years reaped a harvest in the operation of the property. Then, fearing disaster, they sold out at an increase of 25 per cent above the purchase price. This occurred in 1903, since when the property has three times changed hands, and could now be readily sold at a larger figure than was received for it 27 years ago. About one-third of this property remains unflooded.

The history of other leases is similar. Flooding was regarded as an evil until it was shown that a greater quantity of oil could be produced in this way than by ordinary methods in an indefinite time. However, some producers still regard it with disfavor and only take advantage of it in self defense. Some producers have been constrained from flooding their wells by the law which requires that abandoned wells and dry holes be plugged to prevent water entering the sand. This law was construed to prohibit flooding. A recent State law,*** however, removed this restraint.

In addition to intentional flooding, there has been some accidental flooding through improperly plugged holes, leaky casing, etc., as evidenced by the fact that some leases, believed by the purchasers, who were old producers in the field, to be unflooded, were found when drilled to be almost completely flooded.

In recent years the practice of flooding has become very general. Fully 80 per cent of the leases are partially flooded, either from within the lease or from adjoining leases. A rough estimate of the probable area already flooded, including area watered out accidentally, would be about 25 per cent.

Results Obtained by Flooding.

Data have been secured from a number of partially flooded properties near Bradford to show the effect of flooding on production.

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*Manual for the Oil and Gas Industry, Department of the Interior, 2nd Edition - Page 98.
** Thompson, O. F. Tide Water Topics. Vol. 2, No. 4 - April-1920.
*** An Act entitled "An Act of the General Assembly, No. 322," approved May 17, 1921.

Production of 9 flooded properties in Bradford field, in barrels.

No. of Property	Acres Flooded	Natural and Flood Production	Natural Production Without Flood (Estimated)	Production from flooded area.	Production per Acre due to Flooding
1	2.2	11748	1650	10098	4590
2	---	4137	1500	2637	----
3	90	221618	59000	162618	1800
4	6	39022	6000	33022	5500
5	2.6	30980	1825	29151	11200
6	24	-----	----	115000 a	4700
7	24 b	77399	41200	36199	1500?
8	4 c	20168	0	20168	5000?
9	--	6131	0	6131	-----

a. Estimated in part.
b. Probably wrong.
c. Estimated.

If the estimates of natural production without flooding are approximately correct, the figures in this table indicate that the yield is greatly increased by flooding. Wells without natural production have been made to yield thousands of barrels of oil, some producing wells have doubled their output, and others have produced many times more than the quantity delivered before flooding.

Rate and direction of flooding.   The rate at which flooding progresses from a well varies in direction, the speed being greatest where the sand is most open. The water advances most rapidly through the oil sand of wells that produced freely, and moves slowly where wells were least prolific, or, by inference, where the sand is tight.

It has been observed also that the rate of advance of flood water varies with the depth of the well. Flooding seems to progress most rapidly in the deepest wells, as would be expected on account of the greater pressure of the water column. In a lease on the plateau flooding advanced in one direction 112 feet and in another direction 235 feet in a year. In the valley where one watered well is surrounded by 7 producing wells, the flood water has not advanced 175 feet in three years. It is possible, however, that the quantity of water supplied through the one well is not sufficient for the seven.

Method of flooding.   Formerly the method of flooding a well was to remove the casing and plug the well above a known water-bearing sand, leaving the hole open below the plug. This method is in disfavor because, (1) it does not permit examination, and (2) the well may plug itself with silt or chemical precipitates.

As the law requires that the upper sands be protected, the method of flooding a well and of preparing to take advantage of the results, seems to have reached a common practice. The method prescribed and

commonly followed now is to tube the well, placing tubing packer above the oil sand, and cup packers below the water sand. The tubing is perforated above the cup packers. As the tubing may not rest on the bottom it is suspended from the casing head.

Oil wells in line with the flood are cleaned out customarily, sometimes shot lightly, and drilled below the sand to provide a sump in which a larger quantity of oil may accumulate without exerting back pressure on the sand.

Considerable differences of opinion exist regarding the relative efficiency of new wells or old wells, both as watered wells and as oil producing wells. One group advocates the use of old wells for watering, because they are already drilled, flow lines have been developed by the removal of the oil, and the sand has been shattered by repeated shooting. However, paraffine, silt, floating sand, and chemical precipitates may have accumulated around an old well during its life, and tend to obstruct the flow of water outward. These obstructions may be partially removed by a light shot.

These same advocates claim that old wells are more productive when in advance of the flood, because the sand, having been partially drained, offers less resistance to the advancing flood. There is also the possibility of obstruction by the materials mentioned above. They, however, probably offer less resistance to the water, resulting in more rapid drowning.

A second group advocates the use of new wells, both for watering and for producing, because they are clean and without obstruction.

Theoretical Considerations on Flooding Phenomena. Given absolutely uniform conditions in a horizontal sand and equal extraction of oil from all parts, the water entering the sand would occupy a circular area about the foot of the well into which the water was introduced. This circle would widen, carrying in front of it a mass of oil. When the advancing edge of the oil reaches a well, or when a well is drilled into the oil or the water, there is a tendency to flow toward that well. Should the well be drilled within the body of oil, there would be a flow into the well from all directions, including the direction of the well from which the flooding was proceeding, since that part also would be under pressure. The maximum flow would be along the straight line joining the two wells.

The spread of flooding is, roughly, 100 to 200 feet per year.

The circle marking the watered area before the pressure is relieved by a well has a radius determined by the per cent saturation of the sand and the per cent of extraction, but is independent of the porosity.

Advancing flood does not remove all the oil, because due to their differing surface tension with respect to sand, the water cannot displace the oil held by adhesion.

<u>Flood-Drilling Programme.</u>   Various schemes of flooding have been worked out; some advocating a circle of 8 to 10 wells about a single water well, the intention being to put water into this ring of wells when they are drowned out, and drill another ring whose wells are on radii midway between the wells on the first circle and at a distance less than twice the radius of the first circle. This method has the advantage of decreasing the amount of oil trapped, and all the benefit accrues to the lease holder, provided the watered well is distant from the lease boundaries, but probably it will show a less efficient yield per well. Moreover this method has the disadvantage of requiring an increasing number of wells in each succeeding ring, so that a greater proportion of the profits from one ring is used in drilling the next.

Another scheme is to put water into the wells at the four corners of a square of old wells drilled on the old spacings of 400 or 500 feet, and drilling a new square of four wells one placed midway along each side, each new well therefore receiving a double flood. When these are watered out, the program is to drill a center well which will then have the combined force of eight wells and a large drainage area. Outside wells on such a scheme would be a square of twelve wells. There would probably be considerable oil trapped within the first square because the wells on the midpoints of the sides are closer to the central well than the corner wells are. This arrangement would probably have a greater efficiency in barrels per well than the circular form using seven to ten wells, but it also has the disadvantage of an increasing number of wells to be paid for.

A third scheme is to drill a string of wells along a property line, preferably jointly with the owner of the adjoining property, putting water into alternate wells and pumping the intermediate ones. Then each pumping well will have the combined force of two flooded wells. Further drilling would be done opposite the space between wells, each well again having the combined force of two water wells. This scheme has the disadvantage of requiring a large outlay for immediate drilling, which, however, can be cut in half by drilling the first wells jointly with the adjoining property owner. By finding the proper distance for drilling the second row, a large part of the loss due to trapped oil would be avoided and a high efficiency, expressed in barrels per well, would be secured.

All three of these methods are described without consideration of financial expediency, which, in the majority of cases, is paramount. The usual method is to flood an old well, and to drill new wells to take advantage of the flood created. In any drilling scheme to take advantage of flooding the presence of old wells must be taken into consideration.

<u>Prices and Values as Affected by Flooding.</u>   The results obtained by flooding have raised the prices of unflooded land to unprecedented points. Properties have exchanged hands within the last year (1921) at $15,000 per barrel day, and the prices quoted, expressed in dollars per acre, range from $900 to $1350 for leases which some years ago were sold at the value of the casing and tubing in the wells.

A computation shows, however, that these prices may be justified, if there is a good water supply, and the lease is in a pool with an even sand without breaks, soft streaks or other irregularities. Suppose such a lease to be a square of 160 acres and to be purchased for $1000 per acre. With a well spacing of 203 feet, there would be 14 rows of 13 wells each, if both side lines are drilled. Suppose the two line rows to be drilled jointly with the adjoining owner. Then the owner of the 160 acres would drill, pay for and receive oil from 12 whole rows and two half rows, or 13 full rows of wells. The average cost of drilling these would be about $5000 per well, or $845,000 for the 169 wells.

In this method, with the force of two watered wells acting on each producing well, the speed of flooding would approximately require one row to be drilled each year, or the life of the lease would be 14 years. Allowing 10 per cent interest on the original investment, the interest charge would be .10 x $160,000 x 14 years or $224,000. Allowing $10,000 running expense per year (since only one row of 13 wells is producing at one time), the operating expense for 14 years would be $140,000.

Cost of Operating 160 Acres.

Investment	160 acres at $1,000	$160,000
Interest	10 per cent on investment 14 years	224,000
Drilling	169 wells at $5,000	845,000
Expense	14 years at $10,000	140,000
Total		$1,369,000

Estimating the average yield of 4000 barrels per acre, the 160 acres would produce 640,000 barrels, which at $4 per barrel would amount to $2,560,000. Taxes must be deducted. Should the rate of flooding be less than that used, both the interest and operating expenses would be increased.

Unwatering. It is common opinion that flooding marks the end of the productivity of the Bradford sand. Should the price of oil justify it, this sand could possibly be unwatered successfully. As the sand is very fine it offers great resistance to the flow. However, by using a positive pressure as compressed air, to force the oil and water into the producing wells, the water could be removed.

Probable Percentage of Extraction. There seems to be no doubt that even the most successful flooding extracts no great percentage of the oil. If the average porosity of this sand is 18 per cent, and it is completely saturated, this gives roughly 1,400 barrels per acre per foot of sand. Estimating an average of 30 feet of sand and 90 per cent saturation, the original content was 37,000 barrels per acre. Normal yield varies from 2,700 to possibly 15,000 barrels per acre. This same territory flooded yields from 1,800 to 10,000 barrels per

acre. Assuming average conditions, there are removed by normal yield and by flooding probably about 10,000 barrels per acre, which indicates that there remains in the sand about 70 per cent of its original content.

Smith-Dunn Compressed Air Process.

Pressure restoration by means of compressed air and compressed gas has not been widely used in Pennsylvania and precise data are hard to get. This method was once used successfully in Bradford, but was discontinued because the natural gas was spoiled by adulteration with compressed air. The method has been in use in the Third Venango sand near Oil City for a number of years, but no data showing the results obtained were available. Some operators have discontinued its use because the gas is ruined, others because tubing and casing is destroyed. This they believe to be due to the presence of air in the salt water. In most cases, however, the method has been successful with respect to the oil produced. While few data were available from operations in Pennsylvania, the following data were secured from operations in Ohio.

Increase in production of Oil in Ohio by Smith-Dunn Process,
(in barrels)

No.	Natural	Estimated Natural	Total Natural	Actual	Increase	Increase (per cent)	Wells Oil	Air
1	18308	5270	22578	27515	22245	95	?	?
2	16229	2360	18589	13672	11312	61	7	1
3	16500	1735	18235	14665	12930	71	4	1
4	44660	6350	51010	42810	36460	71	17	5
5	23900	4700	28600	8930	4230	14	?	?

Complete captions for the columns in the above table in order from left to right are:

No. of Property.
Natural production prior to use of air.
Estimated natural production from time of application of
    air to date.
Total natural production to date (estimated).
Actual production since use of air.
Increase due to use of air.
Percentage increase due to use of air.

The last two columns indicate the number of wells on each property into which air was forced and of from which oil was pumped.

The data shown in this table do not represent all of the installations and are not known to represent average results. Hence, any average of these figures would be fallacious.

While the spoiling of the gas for domestic use and for use in

lease operation is a great objection in the mind of the operator, yet it would seem that the increased production of oil would greatly offset the expense of buying fuel to replace the gas. However, should the method become so general as to ruin the gas throughout the field a large outlay of capital would be necessary to substitute oil engines for the gas engines used on compressors and pumps. This is probably one of the chief reasons why the method is not in more general use.

In his report, "Methods for increasing the recovery from oil sands," * J. O. Lewis says with regard to a particular property "the production curve of this property and of most of the others where the process has been used long shows a tendency to decline, which if unchecked will make a doubling of total recovery not to be hoped for on the average property in the Appalachian field; and, in fact, is far more likely that if the future does not show greater efficiency the total increased recovery on the average property cannot reach 50 per cent."

Since the data shown herein include production figures through 1920, and since other installations not included in the table are known to be in successful operation, it is considered conservative to estimate that in the Appalachian field an increased recovery on the average property will be 50 per cent of the total natural production.

Unwatering.

The third method of increasing the production of oil is the rejuvenation of old pools or leases by unwatering. Two fields are conspicuous examples of its use: Tidioute, and the famous Petroleum Center-Pioneer fields.

Early Development. Both these fields were early discoveries. The holes were drilled usually by the wet method and before casing was developed or thought to be advantageous. Tubing was inserted and water sealed off by a seed-bag packer.

As the lower part of the Third Venango sand in these two fields was known to contain salt water it was common practice to drill only into the upper oil-bearing stratum.

At Petroleum Center and Pioneer excitement was intense and very small parcels of land were sold or leased, resulting in a large number of wells. When these wells declined to a settled unprofitable production they were abandoned, in some cases without removing the material. These wells permitted the entrance of water to the sand and in a short time the field was flooded out, the flood traveling at the rate of one to five feet a day. Subsequently these fields were practically abandoned.

Recent Developments. About 1904 an effort was made in Tidioute to produce oil from the flooded pool. After pumping water for six

*Lewis, J. O. U.S. Bureau of Mines Bulletin 148, p.76, 1916

months and being ridiculed by everybody, the owner began to produce an increasing quantity of oil. The quantity of oil produced subsequent to the flood is not recorded.

At Pioneer an attempt to rejuvenate oil wells was made about 1917. By drilling to the bottom of the sand, by using a large working barrel and by pumping continuously the water was exhausted and some gas obtained. In order to accelerate the process and to help carry the expense, a vacuum and compressor was installed, which produced some gasoline.

The present procedure is substantially the same. That this is successful is evidenced by the fact that in the first wells drilled into the sand, the water rose 300 feet above the top of the sand, while wells drilled into the sand now encounter no water in the first 15 feet. The entrance of new water through old holes was prevented by plugging many of them. This was further aided by a natural plugging off by silt and a chemical precipitate locally called gypsum.

This rejuvenation, combined with the manufacture of gasoline, has been highly successful, one 100-acre lease showing oil production as follows:

1919	-	47,000 barrels	
1920	-	56,000	"
1921	-	43,500	" (last 2 months estimated)

In addition to this, three gasoline plants were built on this lease, one of which produced 32,000 gallons in November of this year and has been averaging at least 500 gallons per day since September 1919.

Tidioute probably represents the advanced stage in the history of this process. Vacuum is applied universally, new wells drilled in showing "back suction." Oil production has declined to a very small quantity. The continued application of the vacuum has so exhausted the methane, ethane, and propane, that no pressure is required to condense the vapors drawn in the vacuum pumps, gasoline being formed at zero to four pounds pressure. Due to the decline in oil production and the increased richness of the gas, gasoline manufacture has become the chief source of income and the wells are kept open and free of water for the gas they contain. This latter fact prevents the use of compressed air for the production of oil in this field.

Other Fields. This rejuvenation method seems to have an application in a number of the early fields in Pennsylvania which were drowned because of lack of knowledge and equipment. The Pitt Hole pool and the Cooperstown or Glade Mill pool are two examples. It would seem that there is an opportunity for the application of engineering methods in order to take advantage of the considerable water pressure in the flooded sands in these pools. By proper placing of packers or a system of bottom plugging, this water could be made

to force the oil out of the denser part of the sands in which the greater part of the remaining oil is believed to be held and from which it will not be so efficiently removed if the pressure is dissipated by draining the water from the more porous parts.

Cleaning Methods.

Cleaning methods applied to individual wells for increasing the yield from oil pools are numerous. Chief among these are:

1. Squib shooting.
2. Treatment with gasoline or kerosene.
3. Treatment with chemicals, acids, or alkalis.
4. Use of heat producing chemicals.
5. Treatment with hot salt water.
6. Treatment with steam.
7. Use of electrical heating devices.

1. Squib shooting has long been in general practice and consists of a blast with a small quantity of high explosive fired in the well at the oil sand horizon to loosen the rock and accumulated silt or paraffine.

2. Treatment with gasoline or "benzene," as it was then called, was practiced in the early days of the industry when gasoline was a useless product of the refinery. Lately this method has again come into use, kerosene taking the place of gasoline. Kerosene has the advantage of being less volatile and can be sold to the pipe line companies at the price of oil.

The usual procedure is to pump the well dry and pour into it two to six barrels of kerosene. This is agitated for a number of hours by means of a bailer, wedged open, or is left in the well over night. Good results have been obtained.

3. The use of strong acids or alkalis is not common and part of the results obtained by them are due to the heat generated on coming in contact with water. The strong alkalis seem to be able to break up and render fluid emulsions of oil and water and bottom settlings, and are often used in preparing a tank of oil to be run.

4. No case is known where heat producing chemicals have been used, so the results obtained thereby are not known. Thermite, or a mixture of aluminum filings and sodium peroxide, have been suggested. A process of burning out wells with liquid oxygen, to clean them of accumulations of paraffine, etc., has been proposed but no instance of its successful use was found.

5. One case of successful flushing by hot salt water was recorded. Salt water was simply passed through coils heated by gas and run into the well.

6. The use of steam has almost always resulted in a hole full

of water from the condensed steam.

7. Probably the most promising method of cleaning is by electrical heating. At least two types of heaters have been developed, one a carbon rod resistance type, the other an iron-clad, induction type heater. Four wells were treated by the latter type of heater at Washington, Pa. with the following results:

The first well for the first 5 months of 1918 averaged 3½ barrels per week. After treatment in October, 1918, the production was increased to 9 barrels per week, an increase of 135 per cent. In December 1919, this well was still producing 9 barrels per week, and in December 1921, 7½ barrels per week.

The second well during the 10 years preceding treatment, averaged 2 barrels per week. After treatment in November 1918 its production was increased to 4 barrels. In December 1919 it was still producing 4 barrels of oil per week and in December 1921, is producing 3½ barrels.

The third well prior to treatment produced 4 barrels per week. After treatment in the latter part of 1918 its production was increased to 6 barrels per week. It is now producing 4 barrels per week.

The fourth well was producing 12 barrels per week. The first week after heat treating in November 1919 the production was 8 barrels due to caving trouble, the second week it was 18 barrels, and in December 1921, it was 12 barrels per week.

None of the wells has been cleaned or treated in any way since the first electrical heat treatment. This method has not been tried elsewhere.

The electric heater is made of steel pipe, welded, has no breakable parts, and is very sturdy. The heater is lowered into the well attached to the sand line, which serves as a return circuit. An insulated copper cable, which is tied to the sand line at intervals of about 80 feet, carries the current to the heater. The heater may also be attached to the bottom of the tubing, the tubing then serving as the return conductor. The heat treatment is applied for 40 to 80 hours, the current required being 10 K W at 220 volts. The advantage of this heater is that the hot part is on the outside, in direct contact with the fluid in the well. The heater can be used in fields where alternating current is available. Probably the better method, however, is the construction of a portable, gasoline-driven generator set to furnish the power. Such a plant is estimated to cost about $8,000. This plan, however, probably is feasible only for companies having enough wells to justify the cost and to keep the plant in fairly constant operation.

Upper Sands.

In many parts of Pennsylvania, a number of upper sands were

passed through in the original drilling to deeper sands known to be large producers. These upper sands are oil-bearing, but were passed through in order to secure the more prolific flow from sands below. These lower sands having now become exhausted, the upper sands are being tested. Fortunately in most cases the depths of these upper productive sands were recorded and it is a comparatively simple matter to locate and shoot them. In one well a sand estimated to be capable of producing 40 barrels of oil per day was cased off in an effort to reach a lower sand. The lower sand having been exhausted, the casing will now be pulled and the hole plugged as far as this sand.

The results obtained by this method are highly satisfactory. A very profitable producer is obtained at the expense of partially plugging a well about to be abandoned. A single well may yield from an upper sand as much as 15 barrels per day.

Estimate of Reserves.

The petroleum reserves in Pennsylvania are estimated as follows:

1. Future production unaided by improved methods, 35,000,000 barrels
2. Reserves in Bradford pool recoverable by flooding'
                                                   179,000,000   "
3. Reserves in remainder of the State recoverable
               by compressed air   273,000,000   "
                                                        ——————
                                                  487,000,000   "

These figures were derived by the following methods:

1. A curve was plotted showing the production of petroleum in Pennsylvania to 1920, not including the output by flooding in the Bradford field. A projection of the curve indicates a future natural production from all Pennsylvania pools of about 35,000,000 barrels.

2. In the Bradford field the average production to date from 85,000 acres has been about 2900 barrels per acre. This area, while conservative, no doubt includes some very poor and possibly some unprofitable territory. However, a typical lease in the center of the field for which a 38-year production record was obtained shows a yield of approximately 5,500 barrels per acre.

It has been shown that flooding in the Bradford field, after exhaustion by the usual method, will produce 4,500 to 5,500 barrels per acre. If we consider that the average yield of 2,900 barrels without improved methods is too small, as evidence indicates, it is believed conservative to estimate that the field will produce by flooding as much as it produced naturally.

The production of the field has been approximately 251,000,000 barrels, of which 95 per cent, or 238,000,000 barrels was from wells in Pennsylvania. It is believed that 25 per cent of the field has been flooded. If we estimate the remaining acreage to produce 100

per cent of its past production, the reserve in the field is 179,000,000 barrels.

3.   The total production of the State to date has been approximately 750,000;000 barrels, of which 238,000,000 have come from the Bradford field, leaving 512,000,000 as the production of the rest of the State. A conservative estimate of future production without the use of special methods, as worked out by a production curve, is 35,000,000 barrels. This gives a total natural production of 547,000,000 barrels for the State, exclusive of the Bradford field. If we estimate that 50 per cent of this quantity will be produced by the use of compressed air, we have an estimate reserve from the rest of Pennsylvania of 273,000,000 barrels.

It is believed that production obtained by the unwatering method and by cleaning, and from upper sands will approximately replace the losses due to the impossibility of applying the improved methods to small deep pools now abandoned, and no addition is made to the reserve estimate based on these methods.

No mention has been made in this paper of the possibility of obtaining oil by means of shafts and galleries, after the manner of the French in Alsace. This is a possible source of enormous quantities of petroleum, possibly less remote than shale oil. However, this method is not in use in this country, and the results that may be obtained are not included here.